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FLUID RESISTANCE TESTING OF ELECTRICAL WIRE USED IN AIRCRAFT AN--ETC(U)
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FLUID RESISTANCE TESTING OF ELECTRICAL WIRE USED IN AIRCRAFT AND MISSILES

PART IV

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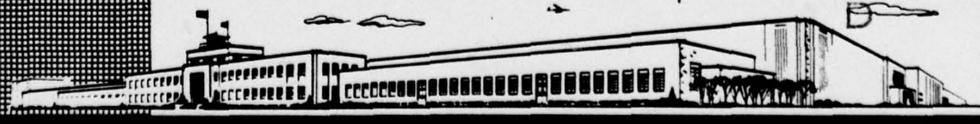

NAVAL AVIONICS FACILITY

INDIANAPOLIS, INDIANA 46218

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PREFACE

This report describes an investigation into the ability of the insulation on aircraft electrical wire to withstand exposure to cleaners which are used on aircraft surfaces. It is a continuation of work reported in NAFI TR-2145[3], TR-2199[1] and TR-2201[2].

This work was performed for NAVAIR under Work Request No. 68E95.

PREPARED BY: W. D. WATKINS

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ABSTRACT

Several types of insulated electrical wire purchased to MIL-W-81044 were immersed in cleaners purchased to MIL-C-43616. The ability of the insulation to withstand degradation by the cleaners was determined by subjecting the conditioned wire to a dielectric withstand voltage test. The electrical insulation DC resistance was also determined.

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I. CONCLUSIONS

1. None of the insulations tested were degraded enough to cause a dielectric withstand failure.

2. Halar® and Kynar® jacketed polyalkene wire resisted the cleaners equally well as evaluated by dielectric withstand testing. However, Halar may have some superiority in regards to DC resistance testing.

3. Removing the Halar and Kynar jackets did not affect the performance in dielectric withstand testing.

4. Kapton insulated wire may fail on naval aircraft after seven to twenty-one years service. More complete field failure reports concerning both Poly-X and Kapton insulated wire are necessary in order to improve this estimate of the service life of Kapton insulated wire.

II. RECOMMENDATIONS

1. The following four wires should be considered for general use in Navy aircraft on the basis of all testing performed to date:

MIL-W-81044/30 and /31 (Proposed)
MIL-W-81044/9 and /12
MIL-W-22759/16 and /18
55A0811

2. It is recommended that a twofold evaluation program be instituted for the above wires. One part would consist of qualification testing of each wire. The second part would involve performing 28 day immersion tests in a broad spectrum of fluids as in the early evaluations done by NARF-NORIS[4].

3. The DC resistance should be determined on a 25 ft. specimen in future solvent resistance testing.

4. In order to obtain a better estimate of the Kapton service life based on the Poly-X service experience it is recommended that:

a. All failures of Poly-X insulated wire on Navy aircraft should be reported, identifying the aircraft type, aircraft BUNO, type of failure (arc-thru, low resistance, etc.), and location on the aircraft.

b. Failed Poly-X insulated wires or cables should be sent to NAFI, D/713, along with a copy of the failure report, with the failed wire tagged or otherwise marked. NAFI will perform further failure analysis and positively identify wire insulation type.

III. INTRODUCTION

In a previous report[1] it was recommended that newly developed polymers used as insulation on electrical wire be evaluated for their resistance to solvent and fluid damage. Two relatively new plastic materials have since been proposed for use in aircraft electrical wire.

One is ECTFE (Halar®) jacketed polyalkene which is radiation crosslinked. This wire is described in specifications MIL-W-81044/30 (Proposed) and /31 (Proposed). It is similar in construction to MIL-W-81044/9 and /12, which is polyvinylidene fluoride (Kynar®) jacketed polyalkene and is also radiation crosslinked.

The other is Irradiated Modified ETFE (Tefzel®) which is radiation crosslinked. This wire is described in a commercial specification and is referred to as Spec "55" wire. It is similar to MIL-W-22759/16 or /18 which are insulated with unmodified Tefzel.

Both Tefzel and Irradiated Modified Tefzel were previously tested[2] for solvent damage by immersion. Both have excellent resistance to damage by high pH fluids ($pH \approx 13$) even at 75° C. There were no dielectric withstand failures after 28 days immersion. The Halar jacketed polyalkene wire was not previously tested.

It is the purpose of this investigation to:

1. Compare the solvent resistance of Halar and Kynar jacketed polyalkene wire immersed at 25°C and 75°C with and without jackets.

2. Measure the DC electrical resistance of the wire insulation during solvent immersion.

IV. MATERIALS

A. Fluids

Two fluids were chosen for this investigation. Fluids A and N are MIL-C-43616 cleaning compounds which were previously employed[1,2,3] and are identified in the same manner as in the previous reports. A complete description of the fluids is given in Appendix C.

B. Wires

Several combinations of two different insulated wires were used. The insulation systems are either Halar or Kynar jacketed polyalkene. They were also tested with the jackets removed. They are identified as follows:

Wire No.	Specification
19	MIL-W-81044/30-20-9 (Proposed)
20	MIL-W-81044/31-20-9 (Proposed)
[illegible]	No. 19 with jacket removed
[illegible]	No. 20 with jacket removed
[illegible]	MIL-W-81044/12-20-9
[illegible]WO	No. 22 with jacket removed

The wires are listed by code number and specification in Tables 1 and 2. A complete description appears in Appendix C.

V. PROCEDURE

The fluids were used in the concentrated "straight from the can" form. Periodically throughout the testing it was necessary to "reconstitute" some of the fluids by adding distilled water to compensate for loss due to evaporation. The evaporation of constituents other than water was assumed to be negligible.

Three specimens from each of the five wire samples were tested in each of the fluids (A and N) for immersion times of 1 through 7 consecutive days, 2 weeks, 3 weeks, and 4 weeks, both at 25°C and 75°C.

The wire samples were cut to 2 foot lengths with the ends stripped on an automatic Eubanks wire cutting machine. The specimens were formed from the 2 foot lengths by making a single turn loop with the ends of the wire run through the loop twice to secure the loop. The loop was formed to a 1 inch diameter on a rod of that size and the stripped conductor ends twisted together. Identification tags were attached to each specimen indicating the wire and fluid code and the time and temperature of immersion.

All specimens (#1, #2, and #3) were immersed in the test fluid in the "as looped" condition.

After immersion, all three specimens were rinsed in tap water and then immersed in 5% salt water for 1 hour. The DC resistance of the insulation was determined after one minute electrification using 500v DC.

Specimen #1 was then immersed for 1 hour in tap water containing an anionic wetting agent. While still in the tap water the insulation was subjected to a 1 minute dielectric withstand test of 2500 volts rms.

Specimen #2 was rinsed in tap water, uncoiled, and allowed to dry for 1 hour at room ambient conditions. It was then subjected to the "double reverse wrap" on a 0.125" diameter mandrel as specified in the solvent resistance test procedure of the wire specifications. Following this, the specimen was formed into a loose coil and immersed in tap water for 1 hour before

being subjected to a 1 minute dielectric withstand test of 2500 volts rms.

Specimen #3 was rinsed in tap water, uncoiled, and allowed to dry for 24 hours at room ambient conditions. Next, it was subjected to the "double reverse wrap" on a 0.125" mandrel, formed into a loose coil, and immersed in tap water for 1 hour. The insulation was then subjected to a 1 minute dielectric withstand test of 2500 volts rms.

VI. RESULTS AND DISCUSSION

A. pH TESTING

The pH of the fluids was as follows:

	Fluid Code	Specification	pH		
			Conc.	1:4	1:9
As Received	A	MIL-C-43616	13.3	11.9	11.6
	N (New)	MIL-C-43616B, Amend #2	9.2	9.2	9.1
After 28 days at 75°C (tested at room temp.)	A	MIL-C-43616	10.4	10.1	10.2
	N	MIL-C-43616B, Amend #2	8.7	8.8	8.9

Aging for 28 days at 75°C significantly lowers the pH of Fluid A and only slightly lowers the pH of Fluid N.

B. Fluid Immersion

There were no failures in either Halar jacketed polyalkene wire (MIL-W-81044/30 or /31, Proposed) or Kynar jacketed polyalkene wire (MIL-W-81044/12) in either of the fluids at 25°C or 75°C.

There were no failures in the above wires with jackets removed and subjected to the same test conditions.

The averages of measured DC electrical resistance values are listed in Tables 1 and 2. The DC resistance of wires immersed at room temperature is lower at the end of 28 days immersion than at the start. This trend is clearly seen for all wires tested in Fluid A (pH = 13.3). It is also seen for wires with jackets removed and tested in Fluid N (pH = 9.2).

The DC resistance of wires immersed at 75°C in Fluid A are also lower at the end of 28 days immersion than at the start.

The daily variation in DC resistance data can be attributed to the short length of the specimen. Only 12 inches of the specimen is immersed and measured for DC resistance. When testing is performed strictly to the specification, the DC resistance is measured on a 25 ft. length. It is felt that future testing of DC resistance after fluid immersion should be done using the 25 ft. specimen.

Curve fitting (with data smoothing) was performed on some of the DC resistance data collected at room temperature and the resultant curves are shown in Graph 1. These curves are useful in showing trends and relative position, but the values of DC resistance shown are not accurate due to the variation in the original data.

It is encouraging that no individual determination of DC resistance on any of the wires was below the minimum resistance specified for cable harness assemblies at the NARFs, $100M\Omega$ ($1 \times 10^{8}\Omega$).

The measured values of DC resistance are lowered by removing the Halar and Kynar jackets about 40% due to loss in material alone. It is obvious that the measured difference is much greater than 40%. It is concluded that both jackets enhance the insulation construction for protection against fluid degradation.

C. Summary

A summary of the results to date of dielectric withstand testing after fluid immersion is given in Table 3. Only wire types currently used or proposed for use are listed.

D. Wire Service Life

Wires 3 and 4 (Poly-X) are purchased to MIL-W-81044/16 and /18 respectively. These specifications were added to MIL-W-81044 on 2 January 1970. The wire was used on the F-4N aircraft, and in September 1975 the first malfunction due to the Poly-X degradation was recorded[5]. The wire could not have been in service more than five years.

Poly-X wire was also used on the F-14 aircraft, which has been operational for about six years. Field failures of Poly-X wire have also been reported for the F-14. While the reports have not accurately established the time of failure, it appears to be no sooner than about three years.

The laboratory tests have indicated that single extruded Poly-X will fail before double extruded Poly-X. The field failure reports do not list which of these caused the malfunction. The preponderance of the wire used in both aircraft is double extruded. But there is doubt as to which one to choose in trying to correlate the three year minumum five year maximum estimate of service life.

Most of the damaged wire found in the aircraft was in SWAMP* areas.

Wires 11 and 12 (Kapton) have been used in the S-3A aircraft, including SWAMP areas, and have been operational for about four years. No field failures have been reported.

Laboratory testing indicated that light weight Kapton (M81381/7) will fail at about the same time as normal weight Kapton (M81381/11) in high pH cleaners. Compared to Poly-X (Table 3, Column 1), Kapton insulation may last from 2.3 to 7 times longer, depending upon whether the comparison is made with single or double extruded Poly-X.

If it is assumed that there is reasonable correlation between laboratory tests and service experience, then Kapton insulated wire may fail after 7-21 years of service. The use of milder cleaning compounds to MIL-C-43616, Amend. 2 (pH ≤ 10) should extend the service life of the insulation.

It is important to be able to predict <u>if</u> and <u>when</u> Kapton insulation will fail in service to determine whether rework may be necessary in present equipment, and to make intelligent decisions in future applications of Kapton. It is necessary to obtain better failure data on Poly-X now in service so that a better estimate of Kapton service life can be made. For the present, Kapton should not be used in SWAMP areas.

In order to determine more accurately the failure history of the Poly-X in service, and thus obtain a better

* SWAMP = Severe Wind And Moisture Problem

estimate of the Kapton service life:

a. All cable harnesses which fail electrically should be reported, identifying the date of failure, the aircraft type, aircraft BUNO, location of cable in aircraft, age of aircraft (or harness) if known.

b. Failed cable harness assemblies (including connectors, if unusable) should be sent to NAFI, D/713, for further failure analysis and positive identification of wire insulation type.

REFERENCES

[1] "Fluid Resistance Testing of Electrical Wire Used in Aircraft and Missiles, Part II", NAFI TR-2199, 11 Aug 1977

[2] "Fluid Resistance Testing of Electrical Wire Used in Aircraft and Missiles, Part III", NAFI TR-2201, 13 Sep 1977

[3] "Fluid Resistance Testing of Electrical Wire Used in Aircraft and Missiles", NAFI TR-2145, 11 Aug 1976

[4] "Fluid Immersion Testing of Aircraft Electrical Wire", Report No. 03-76, NARF-NORIS, 13 Feb 1976

[5] "Investigation of Poly-X Wire Deterioration on F-4N Aircraft", Report No. 01-76, NARF-NORIS, 30 Jan 1976

APPENDIX A

TABLE 1. D.C. RESISTANCE (Ω) AFTER IMMERSION

FLUID	WIRE CODE	MILITARY PART NUMBER	IMMERSION TIME (DAYS) AT 75°C									
			1	2	3	4	5	6	7	14	21	28
A	19	M81044/30-20-9*	1.22×10^{13}	5.67×10^{12}	5.18×10^{12}	4.72×10^{12}	3.29×10^{12}	2.68×10^{12}	2.92×10^{12}	8.53×10^{11}	2.50×10^{12}	2.05×10^{11}
(pH=13.3)	20	M81044/31-20-9*	2.28×10^{13}	1.21×10^{13}	8.64×10^{12}	3.71×10^{12}	4.65×10^{12}	6.59×10^{12}	1.51×10^{12}	2.33×10^{12}	1.56×10^{12}	4.69×10^{11}
	22	M81044/12-20-9	3.89×10^{13}	3.22×10^{12}	2.01×10^{12}	5.11×10^{12}	1.52×10^{12}	9.30×10^{11}	6.20×10^{11}	1.09×10^{11}	3.49×10^{11}	5.19×10^{10}
	19WO	No.19 W/O jacket	3.70×10^{11}	3.45×10^{11}	3.50×10^{11}	-	-	4.10×10^{11}	4.15×10^{11}	6.70×10^{10}	5.00×10^{11}	1.43×10^{10}
	22WO	No.22 W/O jacket	1.02×10^{11}	1.01×10^{11}	6.80×10^{10}	-	-	6.90×10^{10}	4.30×10^{10}	5.60×10^{9}	3.50×10^{10}	2.50×10^{9}
N	19	M81044/30-20-9	-	-	-	-	4.65×10^{12}	6.89×10^{12}	1.19×10^{12}	7.27×10^{12}	3.17×10^{12}	4.55×10^{12}
(pH=9.2)	20	M81044/31-20-9	-	-	-	-	7.64×10^{12}	9.44×10^{12}	2.41×10^{12}	7.81×10^{12}	3.03×10^{12}	1.01×10^{13}
	22	M81044/12-20-9	-	-	-	-	2.65×10^{12}	2.48×10^{12}	1.24×10^{12}	2.91×10^{12}	6.82×10^{12}	2.38×10^{12}
	19WO	No.19 W/O jacket	1.76×10^{12}	1.80×10^{12}	2.70×10^{12}	-	-	2.11×10^{12}	1.93×10^{12}	2.20×10^{12}	2.30×10^{12}	3.70×10^{10}
	22WO	No.22 W/O jacket	1.86×10^{12}	1.28×10^{12}	1.44×10^{12}	-	-	3.05×10^{11}	1.46×10^{11}	1.60×10^{10}	2.15×10^{11}	4.40×10^{9}

* Both M81044/30 and /31 are Halar jacketed polyalkene and are proposed for addition to MIL-W-81044.

TABLE 2. D.C. RESISTANCE (Ω) AFTER IMMERSION

FLUID	WIRE CODE	MILITARY PART NUMBER	IMMERSION TIME (DAYS) AT 75°C									
			1	2	3	4	5	6	7	14	21	28
A	19	M81044/30-20-9*	1.12×10^{12}	-	-	-	-	1.08×10^{12}	1.42×10^{12}	6.10×10^{11}	3.71×10^{10}	3.8×10^{12}
(pH=13.3)	20	M81044/31-20-9*	5.98×10^{12}	-	-	-	-	1.98×10^{12}	2.05×10^{10}	2.09×10^{10}	1.23×10^{8}	1.75×10^{9}
	22	M81044/12-20-9	5.43×10^{11}	-	-	-	-	3.12×10^{10}	1.29×10^{11}	1.14×10^{10}	1.42×10^{8}	8.00×10^{10}
N	19	M81044/30-20-9	4.25×10^{12}	-	-	-	-	3.65×10^{12}	7.00×10^{12}	1.07×10^{12}	1.42×10^{11}	9.00×10^{12}
(pH=9.2)	20	M81044/31-20-9	6.90×10^{12}	-	-	-	-	7.25×10^{11}	4.45×10^{12}	1.84×10^{12}	8.80×10^{10}	11.8×10^{12}
	22	M81044/12-20-9	2.80×10^{12}	-	-	-	-	6.70×10^{11}	4.3×10^{12}	4.3×10^{12}	2.40×10^{10}	3.60×10^{12}

* Both M81044/30 and /31 are Halar jacketed polyalkene and are proposed for addition to MIL-W-81044.

TABLE 3.

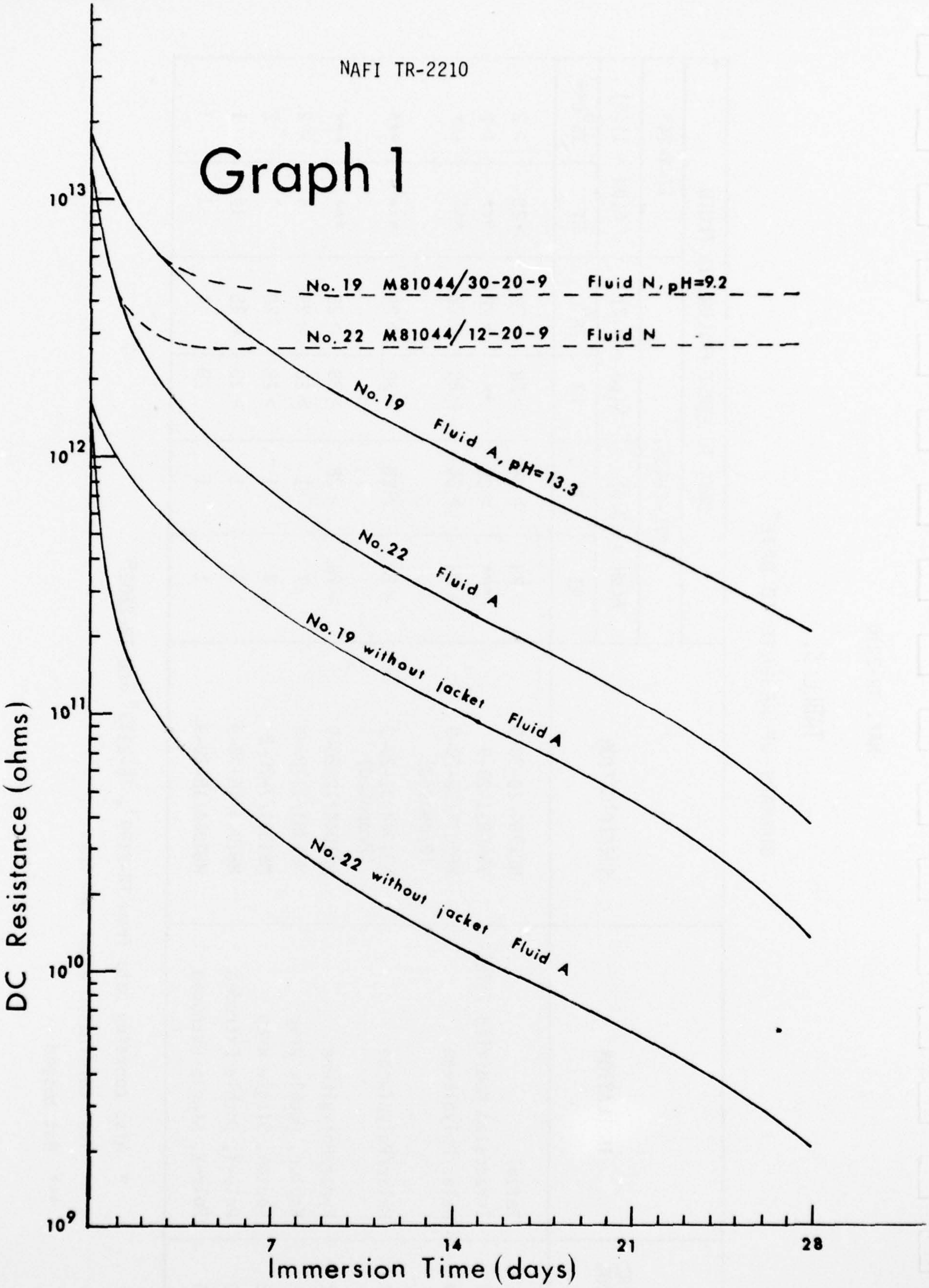
SUMMARY OF RESULTS TO DATE*

WIRE CODE	INSULATION	SPECIFICATION	DAYS TO FIRST FAILURE IN FLUID					
			MIL-C-43616				TT-R-248	
			A(pH = 13.3)		N(pH = 9.2)		G(pH = 11.6)	
			RT	75°C	RT	75°C	RT	75°C**
1	Tefzel	M22759/18-20-9	> 28	> 28	> 28	> 28	> 28	> 2
23	Irradiated Modified Tefzel	55A0811-20-9	***	> 28	***	> 28	***	> 2
19	Halar/Polyalkene	M81044/30-20-9 (Proposed)	> 28	> 28	> 28	> 28	***	***
20	Halar/Polyalkene	M81044/31-20-9 (Proposed)	> 28	> 28	> 28	> 28	***	***
22	Kynar/Polyalkene	M81044/12-20-9	> 28	> 28	> 28	> 28	***	***
11	Kapton, Double Wrap	M81381/11-20-N	7	1	> 28	> 28	4	> 2
12	Kapton, Single Wrap	M81381/7-20-2	7	1	> 28	28	7	2
3	Poly-X, Double Extruded	M81044/16-20-9	3	1	> 28	> 28	14	1
4	Poly-X, Single Extruded	M81044/18-20-9	1	1	28	4	1	1

* Also contains data from TR-2199[1], TR-2145[3] and TR-2201[2]

** Test terminated after two days.

*** Not tested


Graph 1
No. 19 M81044/30-20-9 Fluid N, pH=9.2
No. 22 M81044/12-20-9 Fluid N
No. 19 Fluid A, pH=13.3
No. 22 Fluid A
No. 19 without jacket Fluid A
No. 22 without jacket Fluid A
DC Resistance (ohms)
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
7
14
21
28
Immersion Time (days)

APPENDIX C

APPENDIX C.

DESCRIPTION OF FLUIDS AND WIRES USED

A. FLUIDS

The fluids chosen for this investigation are as follows:

1. MIL-C-43616, "Cleaning Compound, Aircraft Surface". This cleaning compound used by the Navy is water rinsable and required to be 90% biodegradable. The flash point is 142°F (min) and the pH of a 1:4 water dilution must fall between 8.0 and 12.0. The specification does not limit the composition of the cleaner; however, it does list a comparison formula with which to compare the cleaning effectiveness, and a recent amendment (2) limits the pH to 10 max. Two fluids were used: Fluid A with a pH of 13.3, and a new fluid (N) with a pH of 9.2 (both pH's measured in the concentrated form).

B. WIRES

The wires chosen for this investigation are as follows:

1. MIL-W-81044/30-20-9 (Proposed). This is a radiation crosslinked ethylenechlorotetrafluoroethylene (ECTFE, Halar®) jacketed polyalkene insulated electrical wire. It has a tin coated 19 strand copper conductor (AWG 20) and is white (-9). It is similar in construction to MIL-W-81044/12-20-9. The finished diameter is 0.055 inches and is a "light weight" wire. It is identified herein as Wire No. 19.

2. MIL-W-81044/31-20-9 (Proposed). This is identical to MIL-W-81044/30-20-9 wire except the finished wire diameter is 0.070 inches and is a "medium weight" wire. It is similar in construction to MIL-W-81044/9-20-9 wire. It is identified herein as Wire No. 20.

3. MIL-W-81044/12-20-9. This is a radiation crosslinked polyvinylidene fluoride (Kynar®) jacketed polyalkene insulated electrical wire. It has a tin coated 19 strand copper conductor (AWG 20) and is white (-9). The finished diameter is 0.055 inches and is a "light weight" wire. It is identified herein as Wire No. 22.

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13. ABSTRACT

Several types of insulated electrical wire purchased to MIL-W-81044 were immersed in cleaners purchased to MIL-C-43616. The ability of the insulation to withstand degradation by the cleaners was determined by subjecting the conditioned wire to a dielectric withstand voltage test. The electrical insulation DC resistance was also determined.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Insulated wire Cleaning fluids Dielectric withstand Insulation DC electrical resistance Service life						

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